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ROYAL AIRCRAFT ESTABLISHMENT

TECHNICAL REPORT No. 65029

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A BALLOON BARRAGE AS AN AID TO DEFENCE AGAINST VERY LOW FLYING AIRCRAFT (C)

by

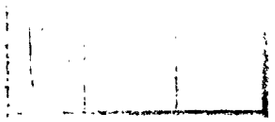
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by

Staff of Mechanical Engineering and Weapons Depts

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SUMMARY

Feasibility of a balloon barrage at low altitude, designed either as a countermeasure to terrain-following radar to force the aircraft up to heights at which they are vulnerable, or as an impact barrage, is considered.

It is concluded that a barrage is unlikely to make an economic contribution when it is impossible to have a set-piece defence. An economic contribution to a set-piece defence is possible only when labour costs are low, when air transport is not needed and when the attacking aircraft can be made to climb.

Under radar terrain-following conditions the radar countermeasure barrage could make the most economical contribution. Because a large portion of the threat is likely to operate under good visual conditions a deterrent to crashing the barrier would be needed by combination of a low-density impact barrage and a radar countermeasure system.

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1 INTRODUCTION

Balloon barrages were used in the early part of the last war to deter dive bombers and, towards the end of the war, as a partial defence against the flying bomb. Practical difficulties limited the barrage to altitudes below 6000 feet with the balloons supporting cables not exceeding 4½ tons breaking load. After the war they were regarded as of no further tactical value because aircraft were intending to fly at great heights, and in any case would fly fast enough to break the balloon cables without serious risk to themselves.

Operationally a new situation has now arisen. Aircraft which attack at high altitude are vulnerable to both fighter and S.A.G.W. defences. By attacking at very low altitude aircraft can largely avoid radar detection and thus reduce their vulnerability. Considerable efforts in many countries are being made towards producing high speed strike aircraft and weapon systems able to penetrate defences and to attack at very low altitude. To obtain a significant advantage to the strike aircraft in this manner, it must fly at heights less than some thousand feet for medium-range S.A.G.W. systems such as Thunderbird or Guideline, and less than a few hundred feet for low-level specialised S.A.G.W. systems such as Mauler. Active defence in this region close to ground level is difficult: by providing a balloon barrage it may be possible to force the strike aircraft to increase its altitude sufficiently to make it vulnerable to nearby S.A.G.W. defences.

This Report considers the feasibility of a balloon barrage at low altitude, designed either as a countermeasure to terrain-following radar to force the aircraft up to heights at which they are vulnerable, or as an impact barrage.

2 RADAR COUNTERMEASURE (R.C.M.) BARRAGE

One function of a low altitude barrage would be to force the aircraft to a height at which the ground defences are effective. This would be done by raising on the barrage an artificial "hill" to the terrain-following radar at a location convenient to the missile defences.

The necessary fail-safe character of terrain-following radar tends to cause the aircraft to rise if any signal return is received from above the ground. This is favourable to a balloon-borne radar reflector system, which should not need so complete a coverage of reflectors as to simulate a solid hill. It may be sufficient to space balloons at intervals of 4000 feet with one reflector of 6 feet side just below the balloon at an altitude of 2000 feet. Even if it proves necessary to use two such reflectors per balloon, the balloons need only

be of about a quarter of the volume of the war-time barrage balloon, making an R.C.M. barrage comparatively economical, as shown in the Appendix.

Corner reflectors can be made light, although accuracy of construction is necessary to ensure equal path lengths for the reflected rays within about $\pm\frac{1}{8}$ inch. Operationally, the simplest arrangement may be to have an inflated radar-transparent spherical cover, over a lightly constructed reflector, suspended from the balloon rigging. Additional reflector spheres could be clipped to the balloon cable as it is paid out. It is important to space the reflectors so that the aircraft radar does not resolve the spacing on closer approach in time to allow the aircraft to drop down through the barrier. It may be more economical to have a double screen in depth of reflectors about two miles apart, using single reflectors on smaller balloons.

3 IMPACT BARRAGE

Although it may not require very much of an impact to cripple a fast aircraft flying at 50 feet, the cables would have to be very closely spaced to ensure that a high proportion of aircraft were stopped. Whilst this requirement may be satisfied by a barrage flying no higher than 500 feet (or perhaps only 200 feet), the close spacing and necessary impact strength to give positive and unambiguous protection make the impact barrage much more expensive than the radar barrage. A hundred miles of arc would certainly not cost less than 10 million pounds, on the basis of impact cables weighing about 20 lb per 100 feet hanging vertically and spaced 50 feet apart.

A physical feature of impact is the critical impact velocity, at which velocity the ultimate strain is generated in the cable. It is a basic characteristic of the material used and is independent of the size of cable. For steel cable this velocity at normal impact is about 600 to 700 feet per second, but many polymers and elastomers appear theoretically to have higher critical velocities. However, from the limited knowledge on these other materials they may be no better than steel in practice because some tend to become brittle at high rates of strain and also suffer from actinic degradation. This latter fact makes them unsuitable for exposure outdoors for a long time.

A cable can be hit obliquely and not break at speeds above the normal critical velocity. A steel cable inclined at 35° to the ground could just withstand impact at 1200 feet per second from a horizontally flying aircraft. About 350 feet of cable are required to impede 200 feet height band above the ground. At these high impact speeds the cable would break at its points of attachment to the ground and to the balloon. Because of this fact it may well be that

controlled cutting of the cable should be practised as in the last war. The impulse applied to the aircraft before the relaxation of the cable would be about 50 lb sec per ton strength of cable. The impulse due to the inertia forces alone of the impact of a 10 ton strength cable on a typical attacking aircraft can be expected to produce an initial rate of roll of about 1° per second. If the cable holds to the aircraft the resultant weight and drag could be made catastrophic. It is important to assess what disturbing forces and impulsive moments must be applied to the aircraft to cause it to crash.

Maintenance of the angles of the oblique cables, and of the spacing between balloons, in all wind strengths and directions, requires that each balloon shall have at least two and possibly three mooring (impact) cables. Although there is some experience of tripod mooring this special case of low altitude oblique cable systems is untried. With multiple cables it becomes feasible to arm with explosives those cables which are not required to be wound by the winch.

4 VULNERABILITY OF AIRCRAFT TO IMPACT

There are certain features about modern aircraft which are favourable to barrage defence and others unfavourable. Among the former, the practice of carrying weapons on underwing pylons provides a forward obstruction of the leading edge to trap the cable. Sweep-back relieves the force of the initial impact and encourages the cable to slip into any recess. Notches intended to break up vortex sheets provide cable traps.

On the unfavourable side, the skin gauge of leading edges is thicker than on the 1940 generation aircraft. The resistance to indentation on impact will be higher but it is not known whether the force of impact at today's speeds would cause an indentation. However, if the impression were sufficient to hold the cable against sliding along the leading edge the velocity of cablewise slip would be so great that it would cut-in catastrophically. Cutting-in was recorded on the early experiments with balloon barrage impact in 1940 but a mild steel leading edge withstood the impact and the cable slid into the Martin Baker cable cutter. Owing to the thinness of modern leading edges any tendency to cut would run deeply, and with the scarcity of space within the wing, vital electrical leads and controls within the wedge of the leading edge may be broken.

Whilst it cannot be claimed that an impact barrage can be operated to stop all low flying aircraft, it may be possible to show that fast low flying aircraft are somewhat vulnerable. This evidence could then be used as a card in the poker game of defence, particularly if it could encourage the opposition to

incorporate protection against wire barrages and thereby penalise aircraft performance. However, it seems unlikely that an enemy would be gullible enough to do this if he has means available for destroying a section of the barrage.

An impact barrage against an unprotected aircraft seems feasible technically, although further investigation would be necessary to substantiate this claim. No means of rendering the protected aircraft vulnerable to an impact barrage is foreseen: with aircraft flying supersonically and able to cut the cable, any explosive device fitted to the cable would be too late in operation for the blast wave to reach the aircraft.

5 COMPARISON OF EFFECTIVENESS OF R.C.M. AND IMPACT BARRAGES

If a wire barrage is proved capable of causing a kill, then the case for R.C.M. is also strengthened because pilots will fear to override the radar control, suspecting that the barrier is composed of "killer" wires.

If a wire barrage is proved incapable of causing a kill, the case for R.C.M. is weaker. In relatively flat country pilots will know that any "hill" is merely an R.C.M. barrage, and in good visibility a determined pilot has a chance of overriding the radar control and of flying through the barrier.

Should the opposition decide to trigger a nuclear weapon on crash of the aircraft carrying it, the resulting damage could be confined to a non-vulnerable area by a suitably sited impact barrage.

The possibility of wrecking the barrage, or some section of it, by an incendiary attack on the balloons has also to be considered, but this will be difficult with aircraft of the performance in mind. In any case, any attack on the barrage, however well timed, is an early warning and could precipitate counter action.

An attempt has been made in the Appendix to forecast the possible scales of cost. Three cases have been considered,

(a) a 100% effective R.C.M. barrage,
(b) a 10% effective vertical cable barrage,
(c) a 10% effective oblique cable barrage.

It is reasonable to consider a 100% effective R.C.M. barrage because the system is automatic against terrain following radar. However, because physical impact barrages have a psychological deterrent it is reasonable to compare at a level of chance less than certainty. The choice of the level is arbitrary and the 10% level is commonly used.

The vertical impact barrage assumes that the aircraft are flying at a speed below the critical impact velocity of the cable, that is below 300 knots, against steel cable (allowing for practical design factors) or at higher speed against an improved type of cable.

The cost for a one hundred mile front of R.C.M. barrage is least, being a quarter of the cost of the cheapest possible 10% effective vertical cable barrage. On the other hand, an oblique cable impact barrage of 10% effectiveness, which is possibly within easiest reach of a practical solution will cost approximately nine times as much as R.C.M. for the same frontage.

With regard to the estimate of manpower backing, this is based on the manning for isolated balloon units. Some automation and common service should be possible with a closely spaced barrage, and a lower level of backing should be practicable.

It would appear to be worthwhile investigating a barrage combining 100% R.C.M. cover with an effective impact capacity of low density to act as a deterrent to crashing the barrage.

6 EFFECTIVENESS OF COMBINED S.A.G.W. (MAULER) AND BALLOON BARRAGE DEFENCES

The comparative merits and demerits of different types of balloon barrage have been discussed in the previous sections. Since balloon barrage by itself is unlikely to cause more than an embarassment to the offence, the provision of a balloon barrage must be justified by the increase in effectiveness of a complementary S.A.G.W. system.

The vulnerability of low altitude strike aircraft to S.A.G.W. defences is very dependent on the flight altitude, and at very low altitudes a small increase in altitude can result in a substantially worse survival chance for the aircraft. The provision of a balloon barrage could force the attacking aircraft to increase altitude. For the purpose of comparing defences with and without balloon barrage it is assumed that the aircraft flies 100 ft above a balloon height of 500 feet (2000 feet for R.C.M. balloon) and when there are no balloons it flies at 100 feet above the ground. The estimates of defence effectiveness are based on a report[1] by British Aircraft Corporation.

With these assumptions the change in defence effectiveness with the addition of balloon barrage can be estimated and hence the contribution to the defence made by the barrage can be compared with the increase in overall defence cost. The overall defence cost will depend on the tactical situation envisaged: for the important case of an overseas intervention operation then three factors

are important:- equipment cost, weight of equipment to be air lifted, and the man power required.

Table 1 summarises, from the Appendix, the costs, weights and man power requirements for various types of balloon barrage plus Mauler S.A.G.W. units assumed to be defending a front (or perimeter) of 100 nm length. An estimate of the defence effectiveness for the S.A.G.W. units combined with differing balloon barrages has been made, thus allowing a comparison of their cost effectiveness.

The various components of cost (capital, manning, transportation, etc) may be combined, as, for example, in recent studies of the cost effectiveness of air defence[2] but for the present it is sufficient to note that, in broad terms, the value (or otherwise) of balloon barrage is indicated by the cost-effectiveness ratios in the above table. The cost (£.s.d.) effectiveness ratio shows that it is unlikely that balloon barrage can make an economical contribution to the defence of a fixed installation unless labour costs are low; for example a town or a main base employing local labour. Where it is not possible to have a set piece defence, for example, defence of the field army or the airhead in an intervention area, the cost of air transporting the balloon barrage would be prohibitive and the man power requirements excessive. The provision of balloon barrage as part of flexible defences is not justified by the increase in the effectiveness of the complementary S.A.G.W. defences since the increase, if required, can be obtained more cheaply by additional S.A.G.W. units.

The comparison of the defences has necessarily been simplified but the results are probably representative even though the density of balloon barrage assumed gives only a 0.1 chance of impact for an aircraft flying randomly through, compared with an increase in vulnerability to the S.A.G.W. defence from 0.2 to 0.4 if it overflies the balloons. In practice, the barrage density could be effectively increased by selective deployment only in those S.A.G.W. areas of fire affected by terrain screening, thus increasing the chance of impact in those areas where the aircraft would otherwise be invulnerable to the defence.

7 GENERAL OFFENCE/DEFENCE CONSIDERATIONS

The calculations of the previous paragraphs have shown for the defence situation examined that

(a) where it is not possible to have a set piece defence, and air transport is necessary, the costs in air transport and man power requirements become excessive,

(b) when there is a set piece defence the balloon makes an economical contribution when the labour costs are low and when the aircraft is made to climb by the effects of the balloons on the terrain avoidance or following radar.

The above present only a small part of the overall picture. The delivery accuracy of H.E. weapons requires operations in conditions when they can be visually aimed. This makes it likely that the aircraft will be flown manually, particularly as intelligence sources would have warned the strike aircraft of the existence of the balloons. In these conditions they will only desire to climb if they should believe that there was some risk of lethality from impact. On the other hand, such intelligence would encourage the offensive to use stand-off weapons (of the T.V. or ARM variety) to neutralise the S.A.G.W. defences before attacking with close range weapons as it would then be possible to fly over the balloons.

8 CONCLUSIONS

(1) Balloon barrage is unlikely to make an economic contribution to air defence when it is impossible to have a set piece defence, with the result that costs in air transport and man power requirements become excessive.

(2) Balloon barrage could make an economic contribution to a set piece defence when the labour costs are low and when air transport is not needed, provided that the attacking aircraft is made to climb.

(3) The R.C.M. balloon barrage appears the most economical contribution but a large portion of the threat is likely to operate under good visual conditions and use visual terrain following, against which the R.C.M. barrage would be ineffective.

(4) In visual following conditions a deterrent could be provided by combination of a low-density impact barrage with an R.C.M. barrage.

(5) At well-defended points, the S.A.G.W. systems could be attacked by stand-off weapons before attack by close range weapons at heights greater than the balloon barrage.

9 INVESTIGATION REQUIRED FOR DEVELOPMENT OF A SYSTEM

The feasibility, or indeed the possibility, of an impact barrage against high speed aircraft has yet to be decided, whereas the R.C.M. barrage is well within known capability of balloon systems. Before a complete system could be made, the following work would have to be undertaken:-

A - Impact barrage

(1) Search of existing technical data relevant to high-speed cable impact, and to the calculable effects of such impact on the aircraft.

(2) High-speed impact tests of cables against representative sections of leading edges of fast modern aircraft.

(3) Flight and handling trials of balloons on tripods and quadrupods of oblique cables.

B - R.C.M. barrage

(1) Theoretical appraisal of the minimum height and spacing of reflectors to have the desired effect on terrain-following radars.

(2) Field trials of a short length of R.C.M. barrage designed in accordance with B(1).

Appendix

APPROXIMATE SCALE OF EQUIPMENT FOR U.L.A. BALLOON BARRAGES

Type of barrage	Vertical, on catenary	Vertical	Oblique	R.C.M.
Balloon volume, cu ft	23000	2500	30000	3000
Distance between balloons, ft	2500	500	2000	4000
Balloon altitude, ft	500	500	500	2000
Cable strength, tons	5	5	5	1
Cable length, ft per balloon	5000	500	5000	2500
Cable weight, lb per balloon	1000	100	1000	75
Number of balloons to protect a front of 100 nm	240	1200	300	150
Number of vehicles for transport and storage of gas (including gas cylinders)	48	24	60	3
Weight of vehicles with cylinders, lb	1 600 000	800 000	2 000 000	100 000
Number of vehicles for transport of winches	240*	125**	300*	38**
Weight of winches and transports together with balloons and cable	6 000 000	1 500 000	7 500 000	180 000
Total weight, per 100 nm	7 600 000	2 300 000	9 500 000	280 000
Total cost, per 100 nm	£2 300 000	£1 350 000	£3 200 000	£360 000
Man power for balloon handling and maintenance, per 100 nm	1200	1200	1800	600

S.A.G.W. (MAULER) COSTS AND WEIGHT

Cost of a Mauler fire unit including a support vehicle plus one reload of missiles, i.e. 18 missiles per fire unit: £565 000

Man power (including element for maintenance in field) per unit: 15

(These estimates are extracted from R.R.E. Memo 1912.)

Weight of a Mauler fire unit:	26700 lb
Weight of a Mauler support vehicle:	18300 lb approx
Total:	45000 lb

* Standard Wilde winch on lorry.
** One Landrover carries four portable winches and four balloons.

Table 1

Defence	Mauler alone	Mauler + vertical impact (catenary)	Mauler + vertical impact (single cables)	Mauler + oblique impact	**Mauler + R.C.M.
No. of balloons	0	240	1200	300	150
No. of Mauler units	10	10	10	10	10
Defence effectiveness against Mach 0.9 aircraft	0.2	0.4	0.4	0.4	0.6
Cost/ - £	5.65 m	8.0 m	7.0 m	8.9 m	6.0 m
*Effectiveness/cost £	1	1.4	1.6	1.4	2.8
Cost - lb wt	0.45 m	8.0 m	2.8 m	10.0 m	0.73 m
*Effectiveness/cost lb	1	0.11	0.32	0.09	1.8
Cost - man power	150	1350	1350	1950	750
*Effectiveness/cost men	1	0.22	0.22	0.15	0.6

* Normalised to "Mauler alone" ratio of 1.

** Assumes aircraft uses automatic terrain following: against visual terrain following defence contribution of R.C.M. balloon could be nil.

/ Costs are based on equipment production cost and do not include operating cost.

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No.	Title, etc
1	The penetration of tactical defence by low altitude high speed aircraft. Tech. Report No.94. By the G.W. Division of British Aircraft Corporation, Bristol, 1963
2	Examination of air defence 1975/85. Tech. Note Weapons 53. M.O.A., R.A.E., Farnborough, March 1964

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